# Physical and biological processes driving seasonal variability of Nitrate budget and biological productivity in the Gabon-Congo upwelling system

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**REVIWER1**

**Dear Reviewers,**

**We would like to express our sincere gratitude for your constructive comments and insightful suggestions, which have greatly helped us improve the quality of our manuscript.**

**Please note the following points regarding the presentation of this document:**

- **Color Coding:** For ease of reading, the reviewers' original comments are presented in **black**, while our detailed responses and the specific changes made to the text are highlighted in **blue**.
- **Figure Renumbering:** Following a specific recommendation from one of the reviewers, the **original Figure 3 has been removed**. As a result, the numbering of all subsequent figures has been updated throughout the revised manuscript. We apologize for any inconvenience this may cause when cross-referencing with the previous version.

Please find below our detailed responses to the comments.

**Review comments:**

Review of Landry Junior Mbang Essome et al. submitted to Ocean science.

"Physical and biological processes driving seasonal variability of Nitrate budget and biological productivity in the Congolese upwelling system."

The present manuscript is aimed at describing the relative contributions of physical and biological processes in modulating nitrate concentrations in the Congolese upwelling system. Although I found the manuscript quite well written, there are some points that need to be clarified (see my comments). Thus, I recommend major revisions to publish this manuscript.

**General comments:**

The paper is generally well written. However, the authors should provide more details and clearer descriptions in several sections (see comments below). I also find it unusual that the authors consistently use the present tense in the Introduction when referring to past studies. I would suggest using either the present perfect or past simple instead.

**Response:** We thank the reviewer for this relevant stylistic suggestion. We have thoroughly revised the Introduction to ensure that references to past studies and findings are now expressed in the **past simple** or **present perfect** tense, rather than the present tense. This improves the clarity and the chronological flow of the literature review. Lines (**101-183**)

In the Discussion and Conclusion sections, I recommend that the authors explicitly cite figures when recalling key results. This would improve the overall readability of the manuscript and be beneficial for readers. In addition, I suggest moving Figure 3 as a subplot within Figure 1 in order to better highlight the study area in the Introduction, and removing the red box currently shown in Figure 1.

**Response:** We thank the reviewer for these suggestions, which significantly improve the clarity of the manuscript.

1. We have thoroughly revised the **Discussion** and **Conclusion** sections to explicitly cite the relevant figures when recalling key results, helping the reader to easily connect the text with our numerical evidence.
2. As suggested, **Figure 3** (standard deviation of nitrate) has been moved and integrated as a subplot within **Figure 1**. This better highlights the regional variability of the Congolese Upwelling System right from the introduction. Line **(185)**
3. The red box in **Figure 1** has been removed to avoid cluttering, as the new multi-panel figure now clearly delineates the study area. **Line (185)**

**2. Modifications in Discussion (Section 4)**

- **Lines (699) : (Fig. 2a,b)** and **(Fig. 4c,d)**.

- **Line (721) : (Fig. 2c,d).**
- **Line (745-747) : (Fig. 7c)** and **(Fig. 7d)**
- **Line (827): Appendix A, Fig. A1**

### 3. Conclusion Modifications (Section 5)

- **Lines (906) : Fig. 4e,f and Fig. 11a**
- **Line (910-911) : Fig. 10c , Fig. 10d and Fig. 10f**
- **Line (919) : Fig. 15**

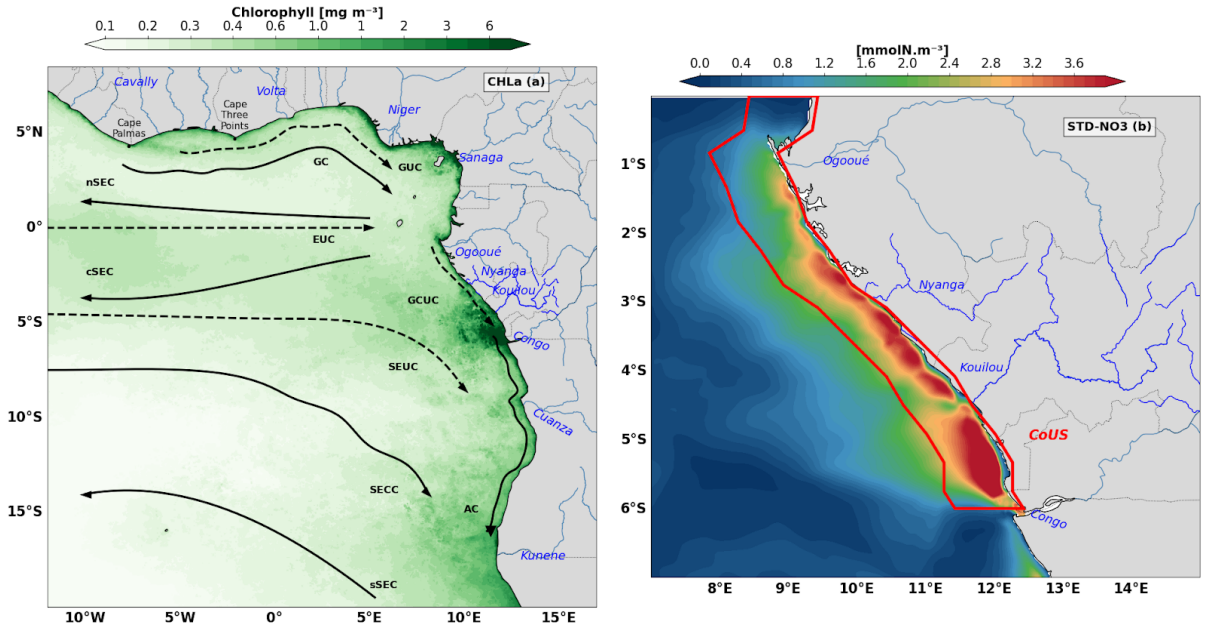


**Fig. R1:** Regional ocean circulation and spatial distribution of biological and nutrient tracers.
(a) Annual mean surface Chlorophyll-a concentration ( CHLa, [mg $m^{-3}$]). The map illustrates the spatial distribution of biological productivity across the Gulf of Guinea and the South Atlantic African margin. Black arrows and dashed lines indicate the major surface and subsurface currents: North South Equatorial Current (nSEC), Central South Equatorial Current (cSEC), South South Equatorial Current (sSEC), Equatorial Undercurrent (EUC), Guinea Current (GC), Guinea Undercurrent (GUC), Gabon-Congo Undercurrent (GCUC), South Equatorial Undercurrent (SEUC), South Equatorial Counter Current (SECC), and Angola Current (AC). (b) Standard deviation of Nitrate concentration ( STD−NO3, [mmolN $m^{-3}$]). The color scale represents the variability of nitrates in the upper ocean. The red polygon delimits the coastal domain defined as the Congolese Upwelling System (CoUS), extending from the Congo River mouth (~6°S) to Cape Lopez (~1°S), which serves as the primary study area for the nutrient budget analysis. Blue labels highlight the discharge points of the Ogooué, Nyanga, Kouilou, and Congo rivers. Line (185)

The choice of the study area also requires clarification. Why did the authors restrict the domain to between 6°S and 3°S? Based on Figures 1 and 3, the northern boundary could be extended to 0°N,

especially since the authors state that the region between 6°S and 0°N is poorly documented (L144). I would suggest that the authors extend the northern boundary to 0°N.

**Response:** We fully agree with the reviewer's suggestion. Initially, the study area (6°S–3°S) was chosen to focus on the core region where major river discharges (Congo and Kouilou rivers) occur and where the highest nitrate variability was observed. However, as noted by the reviewer, the entire region from 6°S to 0°N remains poorly documented. In the revised manuscript, we have **extended the study area box to 0°N** (covering the 6°S–0°N, 1° wide coastal strip). This extension allows for a more comprehensive analysis of the physical and biological interactions across the entire Congolese and Gabonese coastal systems. All figures (Hovmöller diagrams, budget maps, and time series) and associated calculations have been updated to reflect this new domain. Line (**185**)

Regarding the mixed-layer nitrate budget, I can understand the assumption that lateral diffusion term is negligible; however, what about the entrainment term at the base of the mixed layer? This contribution has not been shown or discussed in the analysis and should be addressed.

**Response:**

Regarding the entrainment term, we provide the following details:

1. **Model Calculation vs. Storage:** The entrainment term is indeed calculated internally by the NEMO-PISCES model at each time step (online). However, it was not included in the variables saved in the output files during this specific simulation.
2. **Methodological Precedent:** Our approach follows **Radenac et al. (2020)**, who performed a similar nitrate budget analysis in the tropical Atlantic with the NEMO-PISCES model. Their study demonstrated that the entrainment term is negligible in this region compared to the dominant roles of vertical advection and diffusion.
3. **Numerical Consistency:** To ensure the integrity of the budget, all terms presented in this study (advection, diffusion, and SMS) were computed *online* during the model run. Recalculating the entrainment term *offline* (using saved daily or monthly mean fields of MLD and nitrate) would introduce significant numerical errors and residuals due to time-sampling issues, potentially leading to a misleading interpretation.

**Physical Justification:** In the Congolese Upwelling System, the strong haline stratification induced by the Congo River plume maintains a very shallow and relatively stable mixed layer depth. Since entrainment is primarily driven by the rate of change of the MLD (dh/dt), its contribution remains very small in this specific high-stratification context.

**Action taken in the manuscript:**

We have added a clarification in **Section 2.3 (Methods)** to explain that the entrainment term, although

calculated internally by the model, is not shown because it is negligible in this region, consistent with the findings of **Radenac et al. (2020)**. Line (**267-269**)

To avoid confusion, I recommend removing the acronyms NPP, PP, TPP, NP, RP, as well as AC, and using the full terms throughout the manuscript. These acronyms are used only sparsely and, in several instances, incorrectly (e.g., total PP in L281, new primary production (NPP) in L285, regenerated production (RPP) in L286, or in the title of Figure 18 where NP is used for new primary production, RP for regenerated production, and TPP for total primary production).

**Response:** We have thoroughly revised this part (L754-792) to harmonize the vocabulary and ensure scientific consistency. Following the reviewer's suggestion, we have standardized the terms as follows:

1. **Net Primary Production (NPP):** Used to represent the total carbon fixation rate by both nanophytoplankton and diatoms. This replaces "TPP" and "Net TPP".
2. **New Production (NP):** Specifically refers to the fraction of NPP fueled by external nitrate inputs (upwelling and river discharge).
3. **Regenerated Production (RP):** Refers to the fraction of NPP fueled by recycled nutrients (ammonium).

**Consistency Check:** We have verified that

NPP=NP+RP

across all figures and text. We also ensured that the units (either **mol C $m^{-2}$ $d^{-1}$** for integrated production or **mmol N $m^{-3}$ $d^{-1}$** for local rates) are correctly applied and consistent between the text and the colorbars of **Figure 17**.

**Actions taken in the manuscript:**

We have rewritten the entire Section 3.4 (Biological Productivity) to use this standardized terminology, starting with a clear definition of these terms. Lines (**846-882**)

It would also be helpful if the authors clearly define how the standard deviation and correlation coefficients were calculated in the Methods section. Almost all figures need to be revised. Many figures lack clear boundaries or frames, and colorbars are often too close to the y-axis (e.g., Figures 9, 11, 13), making it difficult to distinguish between latitude/depth and colorbar values. Figures and colorbars should be clearly separated. In addition, I suggest using a finer color scale (more color levels) to better highlight differences.

**Response:**

To improve both the transparency of our methods and the quality of our visual results:

1. **Statistical Definitions:** We have added a dedicated paragraph in the **Methods section (Section 2.3, Lines (305-323)).** to explicitly define how the standard deviation (to quantify seasonal variability) and Pearson correlation coefficients (to evaluate relationships between physical drivers and nitrate concentrations) were calculated.

2. **Figure Revisions:** We have thoroughly updated almost all figures in the manuscript. Specifically:
    - We have added **clear frames and boundaries** to all panels.
    - **Colorbars** have been moved significantly further away from the y-axes to ensure that axis labels (latitude/depth) are clearly distinguishable from colorbar values.
    - We have adopted a **finer color scale** with more color levels to better highlight small-scale differences and gradients in the nitrate budget and biological production.

"The statistical analysis throughout this study relies on the standard deviation (SD) and Pearson correlation coefficients (r). The standard deviation was calculated to quantify the seasonal variability of the nitrate budget terms and chlorophyll-a concentrations across the coastal box. To evaluate the relationship between different physical and biological drivers, Pearson correlation coefficients were computed. For the budget decomposition analysis, the correlation was used to determine the contribution of seasonal anomalies (current or gradient) relative to the total advection term. All reported correlations are statistically significant at a 95% confidence level ($p<0.05$)." **Lines (303-311)**

From Figures 8, 10, and 12, it appears that there may be a discrepancy between the summed contributions of physical and biological processes and the total nitrate concentration tendency. Could the authors clarify this point? Is there a residual term in the budget?

**Response:** We thank the reviewer for this careful check. We would like to clarify that in our study, the **total nitrate tendency is indeed calculated as the exact sum of the physical processes and biological processes.**
The perceived discrepancy is purely a **visual effect related to the colorbar scales**, and we appreciate the opportunity to clarify this point:

1. **Large Compensation:** In highly productive systems like the Congolese upwelling, physical supply (positive) and biological uptake (negative) are the two dominant terms. They almost entirely compensate each other out.
2. **Order of Magnitude:** Because of this compensation, the resulting "Total Tendency" is **one order of magnitude smaller** than the individual physical or biological terms.
3. **Specific Color Scales:** To make the patterns of the Total Tendency visible, we used a much finer color scale (e.g., in Figure 8, the tendency scale is 10 times smaller than the physics/biology scales). If we were to use the same scale for all panels, the Total

Tendency would appear almost uniformly zero (white), masking the important seasonal signal of nitrate accumulation or depletion.

Some figures are not discussed anywhere in the manuscript (e.g., Figures 11c, 11e, 17, and Appendix B), and this should be corrected. I also suggest that the authors consistently use either “Figure” or “Fig.” throughout the manuscript when referring to figures.

**Response:** We apologize for these omissions. We have now fully integrated the discussion of all figures into the text: In the new manuscript, have removed Figure 3 so that figure number was reduced by 1 and caption figure was update in the whole manuscript. for instance, Fig. 11 is now Fig.10.

1. **Figures 10c and 10e:** These panels, representing the zonal and meridional nitrate advection in the mixed layer, are now explicitly discussed in **Section 3.2.1**, where we analyze the horizontal vs. vertical contributions to the nitrate budget. **Lines (524-531)**
2. **Figure 16:** This regional overview of annual nitrate and CHLa concentrations has been integrated into the beginning of **Section 3.4** (Biological Productivity) to provide a broader context for the study area compared to the wider Gulf of Guinea. **Lines (835-841)**

**Appendix B:** The decomposition of nitrate advection (Fig. B1) is now formally cited and discussed in **Section 3.3.2.1** to support the correlation analysis (r=0.77 ).

3. **Consistency:** We have standardized the citations throughout the manuscript. We now consistently use the abbreviation "**Fig.**" (e.g., Fig. 1) except when the word is at the beginning of a sentence, where we use "**Figure**". **Lines (945-947)**

Finally, there is a substantial number of missing references, both in the text and in the reference list, which must be addressed.

**Response** : We have corrected and add the missing reference

**Other comments:**

L3: I suggest that the list of affiliations start with the first author’s affiliation.

**Response:** Agreed. We have reordered the list of affiliations so that the first author's primary institution appears first. The superscripts in the author list have been updated accordingly to match this new order. **Lines (6-14)**

L79: CTWs abbreviation should be used first in L76.

**Response:** Agreed. We have introduced the acronym "**CTWs**" at its first occurrence in the Abstract (L76) and used the abbreviation consistently throughout the rest of the manuscript. **Line (76)**

L111 and L777: It should be: "…(Gutknecht et al., 2013…" otherwise, this reference is missing in the reference section.

**Response:** We thank the reviewer for noticing this omission. We have corrected the citation in the whole manuscript text at **Lines (111 and 878)**. Furthermore, the full reference has now been added to the reference section of the manuscript. **Lines (1041-1044)**

L115: I would suggest to add "South" after "eastern boundary of the …"

**Response:** Agreed. We have added "**South**" to specify that the discussion focuses on the South Atlantic eastern boundary, which improves the geographical precision of the introduction. **Line (117)**

L123: It should be: "… the Angolan coast"

**Response:** Agreed. We have changed "coasts" to singular "**coast**" to improve the grammatical accuracy and consistency of the sentence. **Line (125)**

L134: What do you mean by twhich? Did the authors want to write which?

**Response:** We apologize for this typographical error. "twhich" has been corrected to "**which**". **Line (137)**

L180: It should be: "The red box indicates…".

**Response:** We have corrected the subject-verb agreement in the caption of Figure 1. **Line (193)**

L229: It should be: "…surface wind vector SST dataset. They …"

**Response:** We have corrected the typographical error and clarified the sentence as suggested. **Line (246)**

L247-250: The authors should rewrite these sentences using the correct definitions for each term in the budget.

**Response:** We have thoroughly rewritten this section to ensure that each mathematical term in Equation 1 is correctly and rigorously defined according to standard oceanographic budget analysis. Specifically, we have clarified the distinction between vertical diffusion at the base of the mixed layer and the entrainment term. **Lines (260-271)**

L274: Equation 4 is missing in the manuscript.

**Response:** We sincerely apologize for this oversight. Equation 4, which details the Reynolds decomposition of the nitrate advection terms into mean and seasonal components, was indeed missing from the original submission. We have now inserted this equation in Section 2.3 (Methods) to support the analysis of the drivers of advection variability discussed in the results.

To understand the physical processes driving the seasonal variability of nitrate advection, we perform a decomposition of the advection anomaly. Any variable A (velocity u or nitrate gradient $\nabla NO3$) can

be expressed as the sum of its annual mean ($\bar{A}$) and its seasonal fluctuation ($A'$). The total seasonal variation of the advection term is thus decomposed into three distinct contributions:

$$\mathbf{(u \cdot \nabla(NO_3))' = u' \cdot \overline{\nabla(NO_3)} + \bar{u} \cdot \nabla(NO_3)' + u' \cdot \nabla(NO_3)'}$$

- $\mathbf{u' \cdot \overline{\nabla(NO_3)}}$ **(Current variability):** This term quantifies the impact of current velocity anomalies acting upon a mean (steady-state) nitrate distribution. It isolates the effect of current acceleration or intensification (such as the SEUC or the Angola Current) on nutrient transport.
- $\mathbf{\bar{u} \cdot \nabla(NO_3)'}$ **(Gradient variability):** This term represents the impact of seasonal changes in the nitrate concentration gradient under a mean circulation. It highlights the influence of seasonal water mass enrichment, particularly via the Congo River plume.
- $\mathbf{u' \cdot \nabla(NO_3)'}$**(Non-linear term):** This term accounts for the simultaneous interaction between current fluctuations and gradient fluctuations.

This decomposition is essential for determining whether the "physical pump" (currents) or the "nutrient reservoir" (gradients) drives the seasonal variability of the nitrate budget within the Congolese upwelling system. **Line (294)**

L280: It should be: "… availability. Note …"

**Response:** We have corrected the punctuation and spacing at line 280. A period followed by a space has been added between "availability" and "Note" to improve the readability of the sentence. **Lines (318-319)**

L292: SSH not defined. Also, be consistent between SLA and SSH throughout the manuscript.

**Response:** Agreed. We have added the definition of **Sea Surface Height (SSH)** at its first occurrence in the results section. Furthermore, we have carefully reviewed the entire manuscript to ensure terminological consistency: we use **SSH** when referring to the absolute vertical position of the sea surface and **SLA** when discussing the seasonal variations and anomalies relative to the mean (e.g., signatures of Coastal Trapped Waves).

**1. Corrected Text for (Results Section)**

'The assessment of our model simulation was conducted using several observational products for physical variables, including Sea Surface Temperature (SST), **Sea Surface Height (SSH)**, and ocean currents, as well as biogeochemical tracers such as nitrate (NO3) and chlorophyll-a (CHLa)'. **Line (334)**

L293: I would suggest: "… regional distributions from observations …"

**Response:** We have updated the sentence at line 293 to follow the reviewer's suggestion, which more accurately describes the comparison between the observational datasets and the model results. **Line (336)**

In Figures 2a-b, what could explain the warm bias in the model west of 10ºE?

**Response:**

We thank the reviewer for this observation. While our model uses **ASCAT satellite data** for wind forcing (L199), which significantly improves the representation of momentum transfer and coastal upwelling, the **surface heat fluxes** (shortwave and longwave radiation) are derived from the JRA-55 reanalysis (**212-213**).

The warm bias of approximately 1°C observed offshore (west of 10°E) is primarily explained by:

1. **Overestimation of Shortwave Radiation:** JRA-55, like many atmospheric reanalyses, tends to underestimate the persistent low-level stratocumulus cloud cover characteristic of the South-East Tropical Atlantic. This leads to an excessive amount of downward solar radiation reaching the ocean surface, which cannot be corrected by the ASCAT winds alone.
2. **Heat Flux Feedback:** Since the heat fluxes are partly based on reanalysis, the thermodynamic coupling offshore might not perfectly capture the intense nighttime cooling or the specific diurnal cycle of the open ocean in this region.

L330-331: What could explain the strong nutrient depletion in the model compared to the observations in surface waters, as shown in Figure 4? In addition, Figure 4 shows that the maximum vertical nitrate gradient is shallower and more pronounced in the model than in the observations. Could the authors elaborate on this difference? Does it have any implications for the results or their interpretation?

**Response:**

We thank the reviewer for this technical question. The differences observed in **Figure 4** between the model and the CARS 2009 climatology are primarily due to the limitations of the observational dataset in this specific region:

1. **Data Scarcity and Interpolation:** CARS 2009 is built upon *in-situ* data that is notoriously sparse in the Gulf of Guinea, particularly in the Congolese coastal strip. Consequently, the product relies heavily on objective interpolation, which tends to smooth out extreme values and sharp transitions.
2. **Horizontal Resolution Mismatch:** CARS has a coarse horizontal resolution of **1/2° (~50 km)**, which is insufficient to capture the fine-scale structures of the Congo River plume and the coastal nitracline. In contrast, our model's **1/36° (~3 km)** resolution allows for a much more precise representation of these coastal features.
3. **Vertical Resolution Mismatch:** In the critical upper layers, CARS provides data at 5 m intervals between 0 and 20 m, and then at much coarser intervals (10 m to 30 m) beyond 20 m

depth. Our model uses a much finer vertical grid, with resolutions ranging from **0.5 m to 2.5 m within the first 20 meters**. This explains why the model nitracline is more "pronounced" and shallower: it resolves the intense stratification that the coarse observational grid "blurs" or "deepens" through vertical averaging.

4. **Temporal Mismatch:** CARS 2009 is a multi-decadal climatology (averaging decades of data), whereas our model analyzes a specific year (2011). Climatological averaging inevitably smooths the seasonal peaks of nutrient depletion that a high-resolution snapshot or year-specific simulation can capture.

**Implications:** These differences imply that the model is better equipped than coarse climatologies to study the high-frequency and fine-scale vertical processes (like wave-induced advection) that drive the Congolese upwelling. The sharpness of the model's gradient is a reflection of its superior resolution rather than a fundamental error in its interpretation.

The different parameters and panels described in the caption of Figure 5 do not correspond correctly to the figure. I suggest that the authors carefully check and revise this caption. The x-axis of Figure 6 seems to be cropped.

**Response:**

We thank the reviewer for their careful reading and for spotting these errors.

1. **Figure 4 Caption:** We have corrected the caption of Figure 4 to ensure that the panel letters (a–f) correctly correspond to the parameters shown in the plots. In the original version, the parameters were listed in the wrong order. **Lines (380-381)**
2. **Figure 5 X-axis:** We have adjusted the plot margins and the export settings for Figure 5 to ensure that the x-axis (representing the months of the year) is fully visible and no longer appears cropped. **Lines (430-431)**

L445: It should be: "… (a) and …" Spaces are needed between the figures and the different figures titles in Figures 9, 14, etc… .

**Response:** We have corrected the typo in the caption of **Fig. 8** by adding the word "and" and the necessary space. Furthermore, we have thoroughly reviewed the layout of all multi-panel figures (specifically **Figs. 8, 10, 12, 13, and 15**) to ensure that there is sufficient spacing between the figure panels and their respective titles and captions, as well as between the sub-panel labels (a, b, c, etc.). This significantly improves the clarity and readability of the budget analysis sections. Line (**490)**

L469-471: No possible to see with the actual colobars for Figures 10c-d.

**Response:**

We thank the reviewer for highlighting this visibility issue. We agree that the original colorbars for **Fig. 9c** (physical processes) and **Fig. 9d** (biological processes) were poorly optimized, leading to saturation and making the spatial gradients difficult to distinguish. **Lines (504 )**

To address this, we have taken the following actions:

1. **Optimized Color Scales:** We have redrawn Figure 10 with wider and more precise colorbar ranges for panels (c) and (d). We adopted a **finer color scale** (more levels) to reveal the spatial variability within the Congo plume and the coastal upwelling strip without saturating the signal.
2. **Clear Separation:** Following your general recommendation, the colorbars have been moved further away from the figure panels to prevent interference with axis labels.

**Terminology and Units:** We have ensured that the units (mmolN.m−3.d−1) and the scale values are clearly legible. The text in **Section 3.2.2** has been updated to specifically guide the reader through these improved visualizations.

L480: It should be: "… to the processes …"

**Response:** Agreed. We have corrected the typographical error at line 480 by changing "process" to "**processes**" to ensure grammatical plural agreement, as multiple physical and biological drivers are discussed in this section. **Line (546)**

Are the euphotic layer depth and the nitrate budget in the euphotic layer computed online or offline? I suggest that the authors comment on that in the method section.

**Response:** We thank the reviewer for this request for clarification. To ensure maximum numerical precision and consistency, both the **euphotic layer depth and all nitrate budget terms were computed online** at each model time step (every 5 minutes) during the simulation. This approach, which is the same as the one used for the mixed-layer budget, avoids the significant sampling errors and residuals that occur with offline calculations based on daily or monthly averages. We have added this clarification to the **Methods section (Section 2.3)** as suggested.

L519: It should be: "…period (June, July, …)"

**Response:** Agreed. We have corrected the punctuation and spacing in the parenthetical list of months to improve readability. **Line (587)**

L526: I would suggest to remove "in the euphotic layer". It should be: "… (b) contributed by physical processes (c) and biological processes (d) …"

**Response:** Agreed. We have removed the redundant phrase "in the euphotic layer" from the caption of Figure 12 and revised the phrasing as suggested to improve conciseness and clarity. **Lines (593-594)**

L543: I suggest: “The seasonal cycle of zonal nitrate advection ...” instead of “The zonal nitrate advection seasonal cycle …”

**Response:** We have revised the phrasing as suggested to ensure a more standard and natural academic English structure. **Line (610)**

L544: “<” is missing. It should be “< u >”. Also Is the correlation (r=0.77) statistically significant? If yes, at which confidence level? I suggest to mention it for the other correlation coefficients too.

**Response:** We thank the reviewer for noticing the missing bracket in the mathematical notation; this has been corrected to ⟨u⟩. Regarding the statistical significance, we confirm that the correlation coefficient of r=0.77 is **statistically significant at the 95% confidence level (p<0.05)**. Following your suggestion, we have performed significance tests for all correlation coefficients mentioned in the manuscript (using a two-tailed Student's t-test). In the revised version, we now systematically provide the p -value or a statement of significance for every reported correlation to ensure full statistical transparency. **Lines (606 - 674)**

L547: It should be: “… the term. The …”

**Response:** We have corrected the sentence structure and punctuation at line 547 to remove the redundant phrasing ("the term The third component") and improve the clarity of the description. The text has been split into two distinct sentences as suggested. **Line (614)**

L551: I suggest: “… Undercurrent (SEUC), …”

**Response:** Agreed. We have updated the text at line 551 to correctly place the acronym for the South Equatorial Undercurrent (**SEUC**) in parentheses following its full name. This ensures a more standard and professional presentation of the oceanographic nomenclature. **Line (618)**

I suggest to write “zonal current”, “meridional current” and “verticial current” instead of “current” in the captions of Figures 14, 15, 16, respectively.

**Response:** Agreed. We have updated the captions of **Figures 13, 14, and 15** to explicitly specify the component of the velocity field being discussed (zonal, meridional, or vertical velocity). This clarification has also been applied to the text at lines 567 and 570 to ensure consistency. These changes help to avoid any ambiguity regarding which current component is driving the nitrate advection in each analysis. **Lines (Fig 13 (623), Fig 14 (668), Fig 15 (712))**

L567 and L570: I suggest to write “meridional current” instead of “current”

**Response:**

Agreed. We have updated the text at lines 567 and 570 to replace the general term "current" with the more precise "**meridional current**". This ensures full consistency with the specific advection component (meridional nitrate advection) being analyzed in this section. **Lines (634-637)**

L585: Rephrase the sentence since it is not only the vertical velocity variation term which is expressed in brackets.

**Response:**

We thank the reviewer for this correction. We agree that the term in brackets ($w^{'}.\overline{\nabla z\left(NO_3\right)}$) represents the **contribution of seasonal vertical velocity anomalies acting on the annual mean vertical nitrate gradient**, rather than just the velocity variation itself. We have rephrased the sentence at line 585 to accurately describe this physical interaction. **Line (653)**

L607: By using “consider” at the beginning of the sentence, do you mean “average”. If yes, I suggest: “However, if we average in the upper 100 m, …”

**Response:**

Agreed. We thank the reviewer for this clarification. We were indeed referring to the vertical average over the top 100 meters of the water column. We have replaced the term "consider" with "**average in**" as suggested, which is more scientifically precise. **Line (676)**

L620: It should be: “… budget drivers in the Congolese upwelling system …”

**Response:**

Agreed. We have updated the phrasing at line 620 as suggested. We now use the plural form "**budget drivers**" and the singular "**system**" to more accurately introduce the discussion on the primary mechanisms governing the nitrate balance in our study area. **Line (690)**

L628: It should be: “… surface currents, …”

**Response:**

Agreed. We have added the plural "s" and the missing comma to "**surface currents,**" at line 628 to ensure grammatical correctness and better sentence flow. **Line (697)**

L697: The year is missing in the reference Brandt et al.

**Response:**

Agreed. The year **2023** has been added to the citation of Brandt et al. to correctly identify the reference. **Line (771)**

L744: It should be: “toward” instead of “to ward”.

**Response:** We have corrected the typographical error at line 744, changing "to ward" to the single word "**toward**". **Line (818 and 824)**

L758-766: I am confused by the values and units used to describe primary production, which sometimes do not appear to be consistent with Figure 18, unless a colorbar is missing. For example, a maximum NPP value of 0.60 mol C m-2 d-1 is mentioned. What does NPP refer to here? Is this variable shown in Figure 18? If so, a corresponding colorbar with the appropriate unit (mol C m-2 d-1) should be included, but it is currently missing. Moreover, the value of 0.60 does not appear to be visible in Figure 18. I suggest that the authors carefully revise this section, remove all misleading acronyms (including those in Figure 18), and thoroughly check the consistency of the units.

**Response:**

We sincerely apologize for the confusion caused by the inconsistent use of units and terminology in the biological production section. We have thoroughly revised Section 3.4 and Figure 18 to ensure full consistency.

1. **Terminology Standardization:** Following your previous suggestion, we have removed misleading acronyms. We now consistently use the full terms: **Net Primary Production (NPP)**, **New Primary Production**, and **Regenerated Primary Production**.
2. **Units Harmonization:** The confusion regarding the value of **0.60** stemmed from a mix-up between carbon units (used in the text for comparison with literature) and nitrogen units (produced by the model and shown in the original figures). In the revised manuscript, we have standardized all primary production values to **mol C $m^{-2}$ $d^{-1}$** to allow for direct comparison with other upwelling systems.
3. **Figure 18 Update:** We have updated Figure 18 with clear colorbars and explicitly labeled units (**mol C $m^{-2}$ $d^{-1}$**). The peak value of 0.60 is now clearly visible and matches the description in the text.
4. **Consistency Check:** We have verified all calculations using the Redfield ratio (C:N=6.625) to ensure that the values cited in the text perfectly correspond to the visual data in the figures.

**Lines (846-882)**

Figure A1: The figure is unclear, the y-axes are missing, and the description provided in the caption does not match the different panels shown.

**Response:**

We have thoroughly revised **Figure A1** to ensure it meets the standard of the rest of the manuscript:

1. **Added Y-axes:** We have added clear **Depth (m)** labels and numeric scales (0 to 100 m) to the y-axes of all panels.
2. **Corrected Caption Mapping:** We have rewritten the caption to ensure that the panel letters (a–f) perfectly match the physical and biological processes shown in the figure. In the previous version, the description of the horizontal/vertical sums and individual advections was incorrectly assigned.
3. **Clarity Improvement:** We have increased the resolution and optimized the contrast of the figure to make the subsurface signals more distinguishable.

**Lines (928-936)**

References: Several references listed in the reference section are not cited in the text and should either be cited appropriately or removed. For instance:

- L871-872
- L890-891
- L896-898
- L902-904
- L915-916
- L948-949
- L950
- L968-969
- L989-919

**Response:**

We have thoroughly reviewed the bibliography and the text. For each reference identified, we have either integrated it into the relevant section of the manuscript to strengthen our arguments or removed it if it was redundant. Specifically:

- Removed references (**Gent and McWilliams, 1990; Monod, 1942;Carr, 2002; De Boyer Montégut et al., 2007)**
- **Added references (Aumont and Bopp, 2006**) have been added to the Methods section. **Line (210 )**
- References regarding regional productivity and climatologies (**Ridgway et al., 2002**) have been added to the Method and Results. **Line (238)**
- References regarding stratification and the mixed layer (**Dossa et al., 2019**) have been integrated into the Discussion. **Line (774)**
- **Add Messié and Chavez, 2015:** Introduction . **Line (103-104)**

Citations in the text that are not written in the reference section:

4-

L124: Bachèlery et al. (2015)

L252: Körner (2023) L252

L155: Scannell and McPhaden (2018)

L189: Aumont et al. (1998)

L198: Kobayashi et al. (2015)

L206: Thiam et al. (2024)

L221: Dunn and Ridgway (2002)

L245: de Boyer-Montégut et al. (2004)

L365: Awo et al. (2023)

L400: Bourlès et al. (2004)

L655: Hardman-Mountford and McGlade (2002)

L695: Jouanno (2010)

L714: Johns et al. (2014)

L785: Zang et al. (2023)

**Response:**

We sincerely apologize for these omissions. We have performed a complete cross-check between the citations in the text and the reference section. All 14 missing references identified by the reviewer have now been added to the reference list. Furthermore, we have verified the entire bibliography to ensure that every study cited in the manuscript is correctly documented.

- **Aumont et al. (1998) : Line 988**
- **Awo et al. (2023) : Line 994**
- **Bachèlery et al. (2015) : Line 1004**
- **Bourlès et al. (2004) : Line 1007**
- **de Boyer Montégut et al. (2004) : Line 1026**
- **Dunn and Ridgway (2002) : Line 1038**
- **Hardman-Mountford and McGlade (2002) : Line 1051**
- **Johns et al. (2014) : Line 1063**
- **Jouanno (2010) : Line 1069**
- **Kobayashi et al. (2015) : Line 1071**
- **Körner et al. (2023) : Line 1078**
- **Scannell and McPhaden (2018) : Line 1123**
- **Thiam et al. (2024) : Line 1143**
- **Zeng et al. (2021) : Line 1160**